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Modeling and Simulation of a Standalone Hybrid Microgrid System Using MATLAB Simulink

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ABSTRACT

Hybrid microgrid system is regarded as the part of the core network of electricity system and can also be separated alone from the main grid. According to the load fluctuation such as from 150kW to 250kW and from 250kW to 200kW, the modeling and simulation of a standalone hybrid microgrid system with photovoltaic, wind and battery is analyzed in this paper. For the photovoltaic system, PV array which has total numbers of 580 PV modules is connected with a boost converter. In order to obtain the maximum amount of power from PV array, the Maximum Power Point Tracking (MPPT) technique is used. In the wind energy system, a permanent magnet synchronous generator (PMSG) is with the d-q reference frame used. The wind energy system control is determined by using the Maximum Power Point Tracking (MPPT) technique to obtain the maximum power from continuously varying wind speed. Battery is used as the energy storage device to absorb excess of power and cover shortage of power. The proposed standalone hybrid microgrid system performance is carried out with MATLAB Simulink simulations under standard test condition in which 1000w/m2 radiation, cell temperature 25°C and wind speed is 10m/s.

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KEYWORDS: *Hybrid microgrid; Photovoltaic; Wind; Battery; PMSG; MPPT; Simulation*

I. INTRODUCTION

To generate electrical energy and avoid environmental problems, renewable energies are a solution of this problem, which are produced from natural resources such as sun, wind and water [1]. But the power can't meet the load power demand because renewable energies depend on climatic conditions. Therefore, hybrid microgrid systems are needed. In fact, hybrid microgrid system is composed with distributed energy resources (DER) (photovoltaic, wind turbines) and distributed energy storage devices (DES) (flywheels, superconducting inductors, batteries). This DES are used to absorb excess power and to cover the power shortage. To extract the maximum power from microgrid system, MPPT have been proposed in both photovoltaic and wind system. There are various kinds of MPPT control algorithms for photovoltaic and wind system which are Perturb and observation (P&O), Incremental conductance (INC), Parasitic capacitance, Voltage based peak power tracking and etc. [2]. In this paper, an isolated hybrid microgrid system is described by giving the modeling of each component. P&O is used the purposed control method for an MPPT strategy.

II. System Configuation of Proposed Hybrid Microgrid System

The main components used in the proposed hybrid microgrid system are photovoltaic system, wind energy system which uses Permanent Magnet Synchronous Generator, battery energy storage system and power converters which is used to adapt the voltage between different elements of the proposed hybrid microgrid system. The PV and wind energy system are separately connected with DC-DC boost converters to raise the level of voltage level and attach to the dc bus in order to obtain the accurate dc output without any fluctuations. The battery energy storage system is connected with bidirectional DC-DC converter to charge the battery bank when surplus energy is obtained from renewable energy sources, and discharge the battery bank to supply power to the load when essential. By using of three phase inverter, DC voltage is changed to AC and then AC voltage is given to the load through the AC bus [4]. Figure 1

shows a schematic diagram and the system configuration for the proposed microgrid.

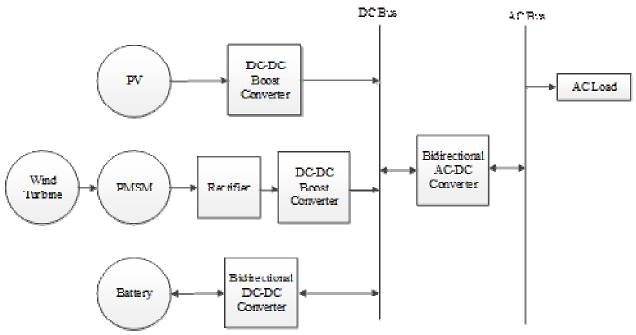

Figure 1. System Configuration of the Proposed Hybrid Microgrid

III. Modelling of Proposed Hybrid Microgrid System

The proposed hybrid renewable microgrid system shown in Figure 1 is composed by photovoltaic, and wind as energy sources and battery as energy storage, accompanied with power converters to adapt the voltage between different elements and to guarantee energy management.

A. Modeling of Photovoltaic Array

The PV array's basic building block is the PV cells. They can convert solar energy directly into electrical energy. The PV array is built by connecting numbers of PV modules in series and/or parallel based on the system's requirement. The PV modules are made up of series connected PV cells and have precise parameters like open circuit voltage, short circuit voltage, diode ideality factor, MPPT operating point, series and shunt connected resistors values and numbers of series connected cells [5]. The equivalent circuit of a PV cell is shown in the figure 2.

The current-voltage relationship of the PV module which contain of series connected PV cells is exposed by the equation below:

$$I_{PV} = I_{ph} - I_s\left(e^{\frac{q(V_{PV}-I_{PV}R_s)}{(N_s A k T_{ak})}} - 1\right) - \frac{V_{PV} + I_{PV}R_s}{R_{sh}} \tag{1}$$

I_{ph}, photocurrent, reliant on solar irradiation and T_{rk}, module operating surface temperature is shown in the following equation.

$$I_{ph} = \left(I_{scref} + K_i(T_{ak} - T_{rk})\right)\left(\frac{G}{G_{ref}}\right) \tag{2}$$

Is , leakage current can be expressed as

$$I_s = I_{rs}\left(\frac{T_{ak}}{T_{rk}}\right)^3 e^{\left(\frac{qE_{go}}{Ak}\left(\frac{1}{T_{rk}} - \frac{1}{T_{ak}}\right)\right)} \tag{3}$$

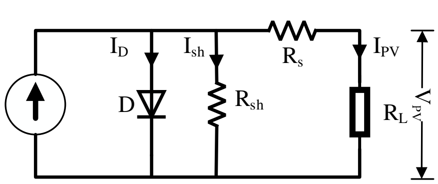

Fig 2. Equivalent circuit of PV Cell

Simulink model of PV array panel is modeled by using MATLAB. This model is shown in figure 3.

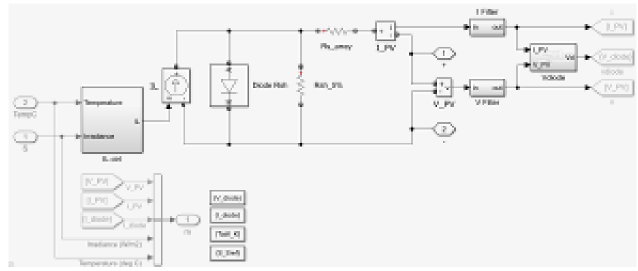

Fig 2. Simulink model of PV array panel

B. Modeling of Wind Energy System

According to the wind movements, the wind turbine can generate required output power [6]. The power output generated by the wind turbine in terms of the aerodynamic power coefficient of turbine, Cp which it can be approximated as the expression of the tip speed ratio, λ and the blade pitch angle, β can be presented as following equation

$$P_m = \frac{1}{2} C_p(\lambda,\beta)\rho\pi r^2 v^3 \tag{4}$$

According to its high rate of efficiency, the Permanent Magnet Synchronous Generator (PMSG) is selected for the wind energy system [7]. PMSG's dynamic modeling in the d-q reference system can be expressed by the following equations (5) and (6).

$$J_t\frac{d\Omega}{dt} = T_m - T_{em} - f\Omega \tag{5}$$

$$T_{em} = \frac{3}{2}p\phi_a i_{sq} \tag{6}$$

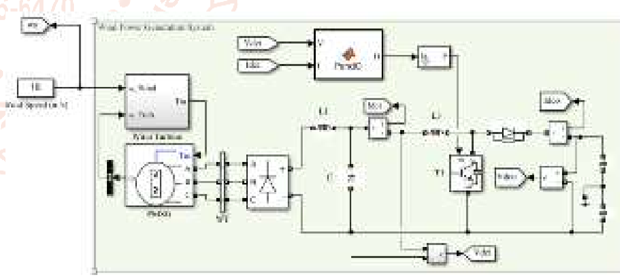

Fig 4. Simulink model of PMSG with wind energy conversion system

Simulink model of wind energy conversion is modeled by using MATLAB. The diagram consists of wind turbine, PMSG, bridge rectifier and also one boost converter shown in figure 4.

C. Modeling of Battery Storage System

The battery storage system which is implemented in this paper is shown in figure 3 and can be modeled with the use of following equation [8].

$$V_{bat}(t) = F_1 - R_{bat}I_{bat}(t) \tag{7}$$

When the battery is charged, battery current Ibat is positive whereas it is negative when discharged. The voltage model necessary able to forecast that the voltage of the battery will reduce gradually and

linearly during the initial part of the discharge and quickly at the end when the capacity of the battery is nearly empty. In the situation of recharging, the voltage rises linearly during the initial part and more quickly to the end of the charge. The require capacity of the battery in ampere-hours (Ah) can be estimated by using the equation shown as below:

$$C_{bat} = \frac{E_L D_{aut}}{DOD_{max} \eta_{bat}} \quad (8)$$

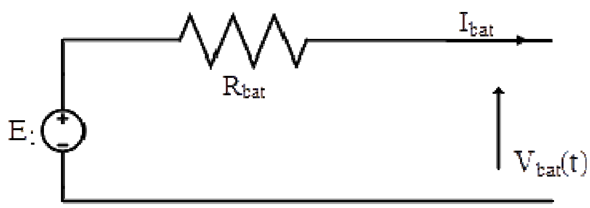

Fig 5. Model of Battery

The battery is connected with a bidirectional DC-DC converter. Battery energy storage system is modelled by using MATLAB according to the stability of the microgrid.

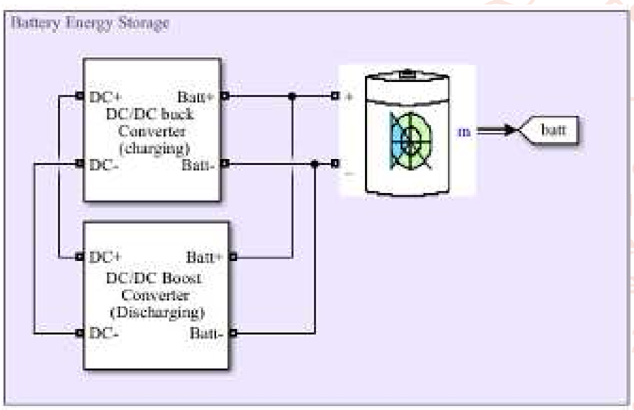

Fig 6. Simulink model of Battery Energy Storage System

D. Modeling of Bidirectional DC-DC Converter

The charging and discharging of battery storage system is carried out by the bidirectional DC–DC converter. In this research, a buck–boost DC–DC converter is implemented for the operation of charging and discharging [9][10]. The configuration of the bidirectional DC-DC converter is illustrated in the following figure 7.

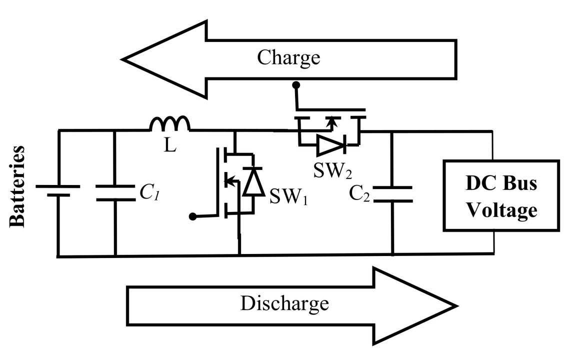

Fig 7. Configuration of the bidirectional DC-DC converter

The bidirectional DC-DC converters can be mode using following equations:

For Boost operation,

$$C_H = \frac{D}{R_H f_s (\Delta V_H / V_H)} \quad (9)$$

$$L_{b,min} \geq \frac{D(1-D)^2 R_H}{2 f_s} \quad (10)$$

For Buck Operation,

$$L_{b,min} \geq \frac{(1-D) R_L}{2 f_s} \quad (11)$$

The boost converter and buck converter of bidirectional DC-DC converter for discharging and charging are modelled by using MATLAB in the following figure 9 and 10.

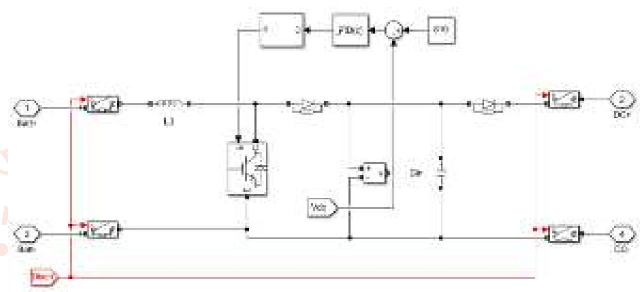

Fig 9. Simulink model of Boost Converter for Discharging

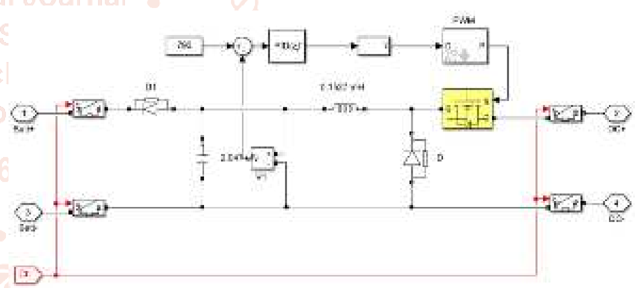

Fig 10. Simulink model of Buck Converter for Charging

IV. Control for Renewable Sources of Hybrid Microgrid

The control for renewable sources of the hybrid microgrid system is analyzed with two portions. They are (1)Control of Photovoltaic Energy System and (2) Control of Wind Energy System with the algorithm flow charts.

A. Control of Photovoltaic Energy System

In order to extract amount of maximum power generation from PV modules, Maximum Power Point Tracking (MPPT) control methods have been implemented. Among five different kinds of MPPT control methods, Perturb and Observe (P&O) method is implemented in this research for determining the PV array's terminal reference voltage value [11]. The algorithm flow chart of Perturb and observe (P&O) for PV energy system is shown by the following figure 11.

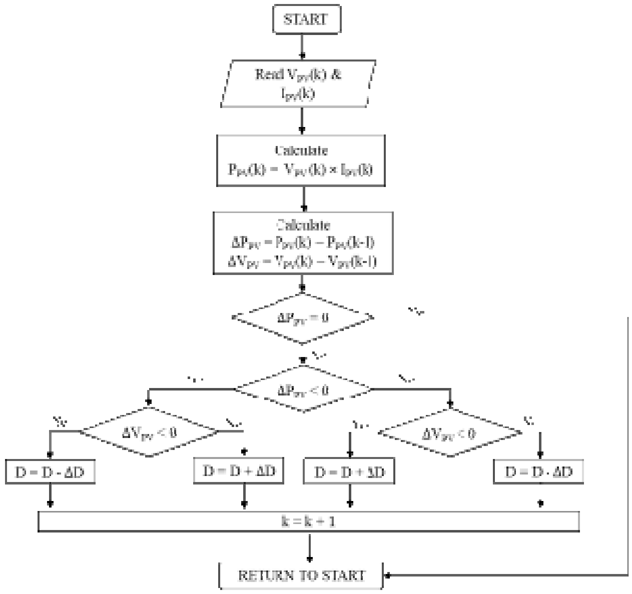

Figure 11. Algorithm flow chart of Perturb and observe (P&O) of PV energy system

B. Control of Wind Energy System

The wind turbine's speed variation depends on its atmospheric situations. Therefore, the PMSG's output voltage and frequency of will be altered as per difference in wind speed. Also, the output of a three-phase diode rectifier will be changed.

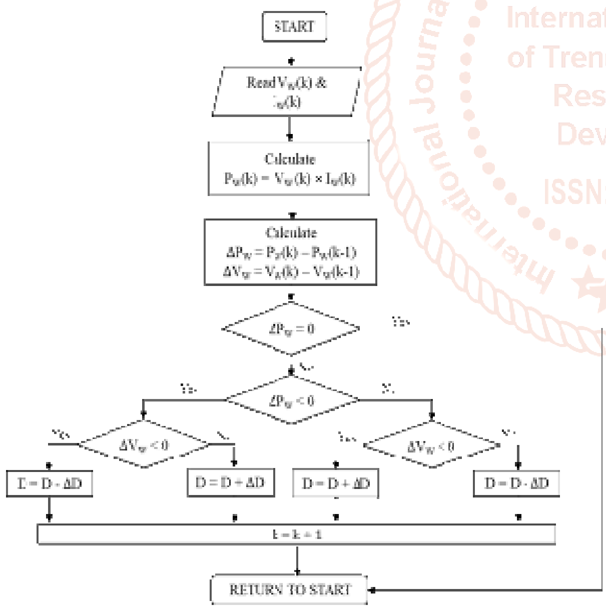

Fig 12. Algorithm flow chart of Perturb and observe (P&O) of PV energy system

Thus, the MPPT control is implemented in wind energy system during a sudden variation in wind speed. There are numerous kinds of methods accessible for MPPT in wind energy system which are Tip speed ratio (TSR), power signal feedback, and perturb and observe (P&O) [12]. Among them, perturb and observe (P&O) is implement in this research. The algorithm flow chart of Perturb and observe (P&O) for wind energy system is shown by the following figure 12.

V. Simulation Results

In this paper, simulation of solar PV, PMSG based variable speed wind energy conversion system battery storage system is analyzed by using MATLAB Simulink. The simulation model of the standalone hybrid microgrid system is modelled by using MATLAB Simulink shown in figure 13.

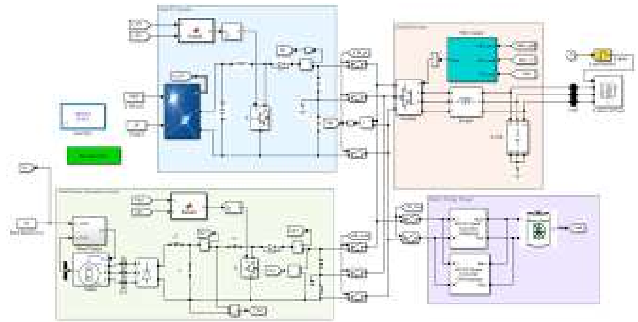

Fig 13. Simulink model of Standalone Hybrid Microgrid System

Power generation from Photovoltaic system is shown in figure 14 and the power generation of wind energy system shown in figure 15.

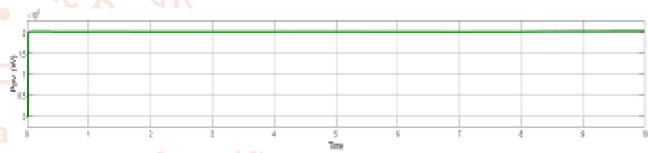

Fig 14. Simulation Result of Power Generation from Photovoltaic System

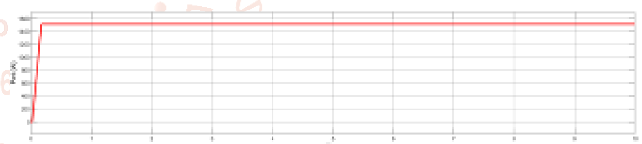

Fig 15. Simulation Result of Power Generation from Wind Energy System

The charging and discharging of the battery storage in the form of current and output voltage curves shown in figure 16 and 17.

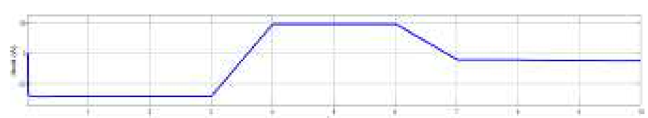

Fig 16. Simulation Result of Current curve for Charging and Discharging of the Battery

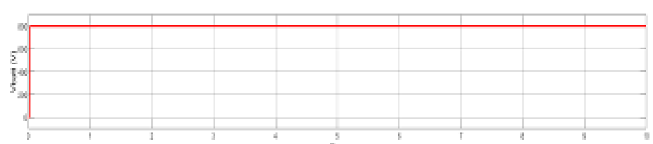

Fig 17. Simulation Result of Voltage curve for Charging and Discharging of the Battery

The power demand curve of the load is shown in figure 18.

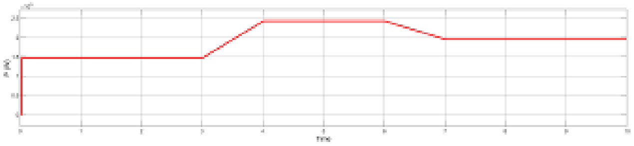

Fig 18. Simulation Result of Power Demand Curve of the Load

VI. Discussion of Simulation Results of Hybrid Microgrid System

The results of simulation are separated into three portions according to the load demand. In the first interval from 0 to 3 sec, the initial load consumed is about 147 kW instead of 150 kW load demand. Wind power generates about 1.5 kW and stabilizing with a slight decrease in PV power up to 202 kW. In figure 19, total generation power is about 204 kW which is greater than load demand and thus in this case, battery is stored the surplus power from this generation.

In the second interval from 4 to 6sec, load demand is increased from 150kW to 250 kW and thus, in this case, the storage power 38 kW from the battery is discharged to compensate for power generation of renewable sources such as photovoltaic energy which remained constant at 202 kW and wind energy system at 1.5 kW.

In the third interval from 7 to 10 sec, load demand decreases from 250 kW to 200 kW and in this case, battery is stored 8 kW from the surplus power of the total generation such as photovoltaic energy which remained constant at 202 kW and wind energy system at 1.5 kW. In the figure 19, the comparison curve is presented the total power generation of photovoltaic system and wind energy system with battery storage and the load demand.

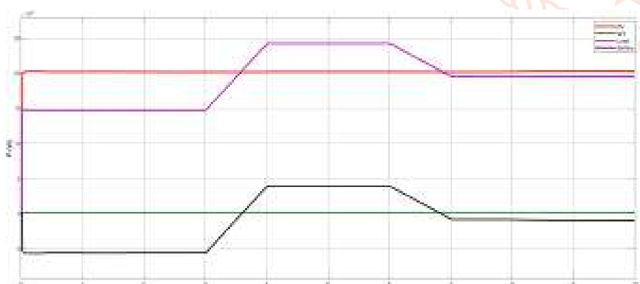

Fig 19. Comparison Curves of power generation of photovoltaic system, wind energy system, battery storage and the load demand

VII. Conclusions

Hybrid Microgrid power system is a vital source of distribution generation source. In this paper, standalone hybrid microgrid which comprise renewable energy offer by wind turbines, PV and battery storage with combined loads is modelled.

From view of power generation balance, the combination of solar PV and wind energy can effectively meet varying load demands when well-coordinated with battery storage. However, due to the intermittency of solar and wind, battery storage plays a critical role in ensuring consistent power supply, especially during periods of low generation or high load demand.

According to battery charging and discharging profile, the battery's charging and discharging behavior shows how it supports the system during generation shortfalls or load spikes. With the load fluctuating between 150 kW and 250 kW, and then from 250 kW to 200 kW, the battery compensates for gaps when generation is lower than demand, and it charges during times of surplus generation. This smooths out power delivery to the load and ensures stability. In scenarios where load demand peaks or generation fluctuates, the battery optimizes energy utilization, reducing wastage and enhancing system efficiency.

From the point of view from renewable penetration and sustainability, the hybrid microgrid setup demonstrates the potential for high renewable penetration in meeting local demands without reliance on conventional power sources. This configuration not only supports sustainability but also minimizes operational costs associated with fossil fuel usage.

Therefore, from the modelling and simulation of a standalone hybrid microgrid system with solar PV, wind power, and battery storage, the power output of each generation source alongside the charging and discharging profile of the battery and load demand fluctuations provides to the system stability, reliability, and efficiency.

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